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ED 474 507 SE 067 390

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| AUTHOR | Farnsworth, Ralph Edward |
| TITLE | Mission Mathematics Proportional Reasoning: Bridging and Stimulating a Diverse Student Population with the Mathematics of Space. |
| PUB DATE | 1999-00-00 |
| NOTE | 7p.; Paper presented at the Delta Conference (Australia, 1999). |
| PUB TYPE | Reports - Research (143) -- Speeches/Meeting Papers (150) |
| EDRS PRICE | EDRS Price MF01/PC01 Plus Postage. |
| DESCRIPTORS | Age Differences; Concept Formation; Curriculum Design; Higher Education; Mathematics Instruction; Secondary Education; *Space Sciences; *Thinking Skills |

ABSTRACT

This paper discusses the use of proportional reasoning and the mathematics of space to help bridge the gap from secondary school to university while stimulating the interest and mathematical appetite of a diverse student population. The five goals of NASA's Mission Mathematics program are adopted. An interactive lesson used with freshmen university students is presented. Additional applications and suggested follow-up lessons are listed. (Author)

# Mission Mathematics: Proportional Reasoning. Bridging and Stimulating a Diverse Student Population With the Mathematics of Space

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This paper discusses the use of proportional reasoning and the mathematics of space to help bridge the gap from secondary school to university while stimulating the interest and mathematical appetite of a diverse student population. The five goals of NASA's Mission Mathematics program are adopted. An interactive lesson used with freshmen university students is presented. Additional applications and suggested follow-up lessons are listed.



## Introduction

In our attempt as educators to bridge the gap between secondary school and university study, we strive to find ways to motivate a student population diverse in background and ability. We must rise to the challenge to help students develop their analytical and problem-solving skills by making them think, question, and probe, rather than blindly repeating memorized algorithms. Students can not learn mathematics by only listening, reading, and discussing. They must actually do and think mathematics. To accomplish this we must motivate them to want to do mathematics. Our students believe mathematics stopped with Euclid. We need to show them that mathematics is alive and growing and very much an integral part of their lives. This is where the mathematics of space can capture their attention.

Through my work with NASA, this program came into being. The materials and support available through NASA make each lesson come alive and provide an endless supply of topics and motivation. The goals of the NASA Mission Mathematics program match my own, and so they have been adopted as the goals of this proportional reasoning program.

The program has been used with freshmen university students in the United States and with two workshop gatherings of faculty members as well. The freshmen were in general, introductory, compulsory mathematics courses. Many of them suffered from "math phobia" or "math apathy". After the program, they were not only interested in mathematics, they were talking mathematics and using proportional reasoning with ease. The students were active participants in the lessons and not passive, disinterested note-takers. With each lesson the instructor can spot areas of weakness, such as time flow and adequate use of materials, and make corrections. Based on student feedback the instructor can adopt additional or alternate topics of interest to the students and make the program a continuous work in progress.

Two faculty groups were each given a two-hour inter-active presentation of the lesson discussed in this paper. According to their summary reviews, they enjoyed it, saw the benefits, and intended to incorporate it. I would recommend the program be used at some level in every freshman mathematics course, regardless of major, because proportional reasoning is a skill worth cultivating and space is a wonderful topic of interest.

## Program

The five goals involved in stimulating student interest and bridging the transition from secondary school to university for a diverse student population are the same as those of NASA's Mission Mathematics Program.

1. Present significant mathematics.
2. Engage students in reasoning and problem solving.
3. Lay a conceptual foundation for understanding mathematical ideas.
4. Show contemporary applications of mathematics in context and methodologies.
5. Motivate and inspire every student, [1].

As educators, we ask questions of students, as did Socrates, but more importantly we need to inspire students to ask and investigate questions of their own. There appears to be a critical need to strengthen estimation and analytical skills through comparative relations and proportional reasoning. Without these skills, I feel that students will have little chance of success in university mathematics courses.

We can stimulate student interest by exploring exciting non-traditional questions. At a time when interest in space exploration is at a high due to current events and recent movie releases, the mathematics of space is ripe and should be plucked.

It is my experience that, on several levels, many students are especially weak in the area of three-dimensional and spatial estimations and comparisons. Their visual and cognitive comparisons frequently appear limited to linear measures. As one might expect, large numbers also have little meaning to students until put into a proportional reasoning context by comparing the numbers to something students can visualize within their own frames of reference. Once a proportion has been realized, students seem to grasp the relationship quickly and work well with it.

One person's idea of "large" is not the same as another's. If we explain, for example, how big the building is which houses the NASA space shuttle and its rockets while preparing for a launch, we can not adequately convey by mere words the enormity of the building. This building is known as the V.A.B. or Vehicle Assembly Building.

Drawing a large prism on the board, like Figure 1a, and expressing various superlatives still does not meet the task. There is no perspective. It is not until we add another factor for comparison (such as the door humans enter, Figure 1b) that the size becomes meaningful. This is usually enough to make the point.

We must find creative ways of measuring and comparing to put things in a perspective meaningful to each student. The following lesson accomplishes this task through the proportional reasoning involved in the mathematics of space.

This lesson is considered a first lesson for university freshmen and is appropriate for an introduction to proportional reasoning. It is listed as a "how to" lesson plan in four phases for instructors to emulate and is followed by suggestions for further lessons. Because this introductory lesson is designed to help with proportional thinking and estimation of large numbers, many numbers are rounded off or specifically selected to allow for convenient ratios. In this non-threatening environment of numbers, students are not frightened off and actually get involved in the lesson.

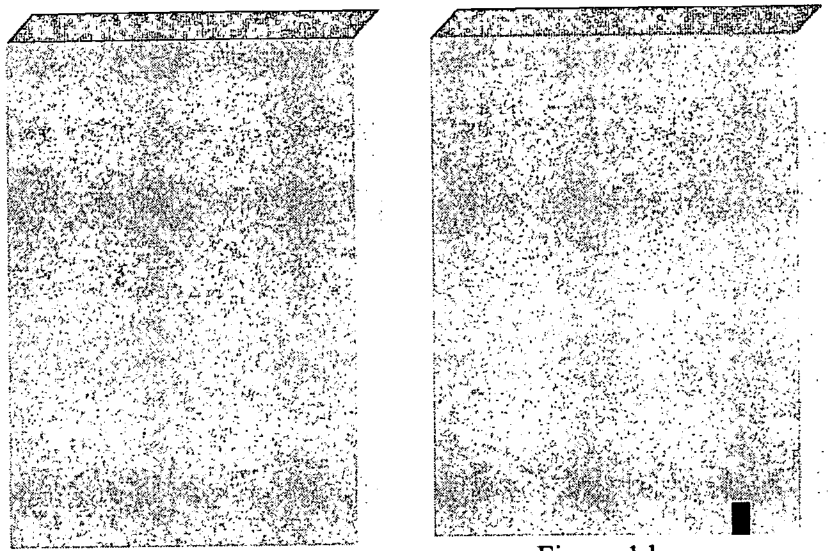

Figure 1a Figure 1 b

Figure 1: (a) V.A.B. houses Shuttle and Rockets – (b) Human Entry Door on V.A.B.

## Lesson: Proportional Reasoning in Space

**Phase 1:** In this lesson hold up a three-dimensional spherical model of the Earth and place other spheres of assorted sizes in a random arrangement on a table. With no information given ask students which sphere represents the Moon. It is important not to line up the spheres in order of size. Do not use a yellow sphere because students are automatically drawn to it as the Moon. Next, present a small amount of information, namely, that the ratio 1:4 has "something" to do with the comparison. After selections have been altered or reaffirmed, explain that the 1:4 is a linear, Moon to Earth, ratio which compares r:R, d:D, and c:C. Assist students in the final selection and ask them how they could verify that their choice meets one of the 1:4 ratios required. The discussion usually ends with a suggestion of stacking four identical spheres to see if their diameters total that of the original sphere and another suggestion of placing a string around the equator of the small sphere and comparing it to a string around the equator of the Earth. This is a good time to remind students of how areas and volumes of similar objects are related. Explaining to them that the ratio of areas must be 1:16 (the square of the linear ratio) and that the ratio of volumes must be 1:64 (the cube of the linear ratio), may put the situation into more of a perspective for students.

**Phase 2:** With no additional information ask students where to place the Moon in relation to the Earth in order to maintain the proportional distances used in phase 1. After many revealing guesses, give them two facts: the circumference of the Earth is approximately 25 000 miles and the distance from the Earth to the Moon is approximately 250 000 miles. [1, p.3-8] Ask students how these two numbers are related. After a 1:10 ratio is established, ask students how they could use this information to more accurately place the Moon in relation to the Earth. Students usually suggest using a string again to get the circumference of the Earth and then measure it out end-to-end ten times until they have a long string representing the correct position of the Moon. This is a hands-on group activity, which gets many students involved and typically does not lack volunteers. When students see how far from the large sphere the small sphere representing the Moon must be held, the shocked expressions on their faces are priceless.

**Phase 3:** With no information given, ask students where to place the space station and shuttle orbit between the Earth and the Moon. It is amazing how many students place the station and shuttle halfway or at least one-quarter of the way from the Earth to the Moon. Next, tell the students that the distance from the Earth to the station and shuttle orbit is approximately 250 miles and remind them that the Moon is 250 000 miles from Earth. Ask them how these numbers compare. Students are typically amazed to find that the ratio is 1:1000, which places the station and shuttle orbits about the thickness of a hand away from Earth. When asked, students suggest either cutting the Earth to Moon string into 1000 pieces or cutting the circumference of the Earth string into 100 pieces, which would allow for a brief discussion of percent.

**Note:** With this proportional perspective fresh in their minds and their attention firmly planted on the lesson, it is time to move to phase 4. In this phase they will actually do mathematics by blending tables of data, graphing, functions, spreadsheets, pattern recognition, predictions, and writing. In other words, they will use proportional reasoning and mathematical modeling.

**Phase 4:**

**Encapsulated version:** Discuss the problem of the continuous accumulation of space "junk" or debris left in orbit by mankind. Involve students in a project of mathematical modeling. Present a scenario in narrative form with a few facts that could be translated into a table of data. Students can create the table by hand and in spreadsheet form with the help of a program such as Excel or Lotus. Ask students to predict the behavior of the graph of the data in the table or spreadsheet and to find an equation representing the graph. Discuss how changes would affect the table, the graph, and the equation. Vary and extrapolate the scenarios to predict the future extent of the problem of space debris. Have students report the results and their suggested solutions to the problem in writing.

**Full version:** In the orbit of the space station and shuttle, there are tens of thousands of small untrackable pieces of "junk", much of which is the size of a grain of sand. In addition, there are 10 000 or more pieces of space debris, golfball size or larger, currently being monitored as they orbit the Earth. All of this jetsam is traveling at a rate of 17 500 miles per hour. Many of us know the biting cuts sand can make to our skin and to automobile body paint when the wind is 50 miles per hour or more. Imagine the damage it can do at 17 500 miles per hour.

In 1990 scientists estimated that a total of four million pounds of debris was in Earth orbit. They also estimated that, at that time, humanity was adding 1.8 million pounds per year to the already serious problem, which in a few years would reach 9.5 million pounds of orbital debris. The 1990 prediction also stated that the amount of debris being added per year was anticipated to increase to a rate of 2.7 million pounds per year by the year 2000, [1,p.17-34].

This is a perfect opportunity to ask "what if" type questions, such as what if the rate stayed at 1.8? What if it were at 2.7 the entire time? What if it stayed at 1.8 until the year 2000 and then changed to 2.7? What if it steadily increased from 1.8 to 2.7 by the year 2000?

What if we looked well beyond the year 2000? Each of these questions elicits a table of data which can be compiled by hand or calculator, or entered into a spreadsheet. Each also has an equation and corresponding graph which may be predicted, calculated, and analyzed. The students can discuss slope of a line, acceleration of a constant rate of growth, first, second, and third constant differences, and linear and quadratic behaviors. This involves the entire class and typically stimulates a great deal of interest and questions. Students can be divided in three groups. In group one some of the students will do the calculations, some will record the results in a table of data values, and others will plot points on the "board" or transparency paper. Meanwhile the second group of students can produce a spreadsheet of values, utilize the built-in graph generator, and then examine the data to produce equations to represent the scenarios. The third group can be maintaining a narrative summary chronicling the work of the other groups and then offer suggestions on how to solve the problem.

Discussion of the proposed solutions, such as reducing the debris by ten percent per year through clean-up efforts in the face of the yearly accumulation taking place, can lead to new data and graphs. A good question would be what rate of yearly clean up would be needed to finally reverse the increase in debris and then lower the total amount of debris to a point below the 1990 level. A comparison to the problems of local landfills and city dumps would be appropriate. This lesson stimulates the students much more than the usual questions found in most textbooks about the population increase rates of lemmings or bacteria. The proportional reasoning used in determining if the graphs were linear or quadratic, predicting how much debris would accumulate by certain arbitrary dates, and offering solutions which would be realistic and timely, will greatly add to students' interest and confidence in both mathematics and their own reasoning abilities.

### Follow-up Lessons:

Other lessons should follow which deal with additional space related issues. The vectors involved in the free-fall of orbital flight, resulting in micro-gravity, is a favorite among students. The way in which drop-towers simulate micro-gravity and the fact that there is no micro-gravity "room" is a good link to the orbital lesson. [4] Space flight paths for travel between planets moving in different orbits and at different rates, resulting in limited windows of opportunity for launch, always prove to be a popular lesson. Locating the relative positions of the planets from the Sun, based upon a table or spreadsheet of values, by pacing out the distances or by locating them on a map as relative distances between two fixed locations, is always an eye-opening lesson for students. Discussion of the GPS (Global Positioning System) and the way its system of satellites uses the intersection of spherical distances to pinpoint a location provides students with yet another example of spatial relations and proportional reasoning. [5]

### Summary

When dealing with a student population diverse in background, ability, training, and motivation, the task of bridging the gap between secondary school and university can appear Herculean. It is incumbent upon us, as educators, to stimulate interest in mathematics and foster a sense of understanding, achievement, and relevance. The use of proportional reasoning, which builds skills in estimation, pattern recognition, prediction, spatial relations, and mathematical modeling, is a vital early link in the process. The mathematics of space is ideal for garnering student interest and provides ample opportunity to develop proportional reasoning skills. University freshmen in the United States, who participated in this program, showed signs of higher interest in and understanding of the mathematics of the world around them. Although this program is undoubtedly most effective on non-mathematical students and students whose diverse backgrounds have left significant gaps in their preparation for university study, it is also beneficial to those who may need merely to hone their estimation and logical reasoning skills. As I remind my students: "Space — the Math. is out there."

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